

REGRADED UNCLASSIFIED BY ORDER

SEC. ARMY BY Ltr. 4/27/56, from Adjutant General,
AGAO-S 312.1 Security
(J1972)

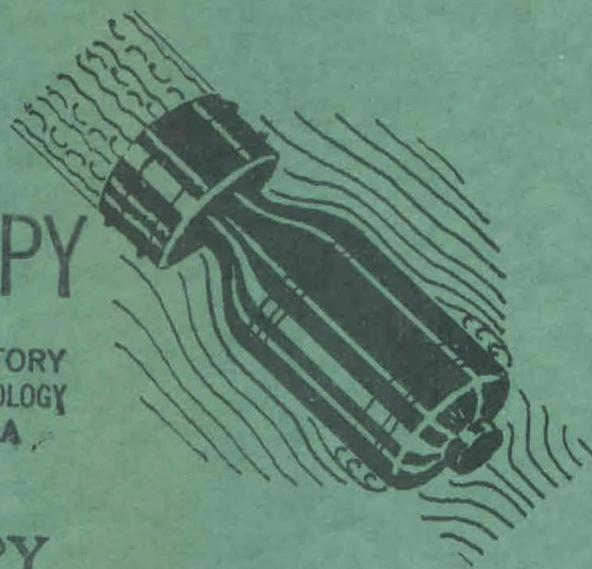
~~CONFIDENTIAL~~

OFFICE OF SCIENTIFIC RESEARCH & DEVELOPMENT
NATIONAL DEFENSE RESEARCH COMMITTEE
DIVISION SIX-SECTION 6.1

MK. 25 TORPEDO WITH VARIOUS EXHAUST PIPES

LIBRARY COPY

OF THE
HYDRODYNAMICS LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA 4, CALIFORNIA



LIBRARY COPY
PLEASE RETURN

THE HIGH SPEED WATER TUNNEL
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

SECTION No 6.1-Sr207-2236
LABORATORY No ND-30.3

~~CONFIDENTIAL~~

COPY No 94

LIBRARY COPY

OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT
NATIONAL DEFENSE RESEARCH COMMITTEE
DIVISION SIX - SECTION 6.1

MK 25 TORPEDO
WITH
VARIOUS EXHAUST PIPES

ROBERT T. KNAPP
OFFICIAL INVESTIGATOR

THE HIGH SPEED WATER TUNNEL
AT THE
CALIFORNIA INSTITUTE OF TECHNOLOGY
HYDRODYNAMICS LABORATORY
PASADENA, CALIFORNIA

Section No. 6.1-sr207-2236

Laboratory No. ND-30.3

Report Prepared by
Harold L. Doolittle
Hydraulic Engineer

July 4, 1945

This document contains information affecting the national defense of the United States within the meaning of the Espionage Act, 50 U.S.C., 31 and 32, as amended. The transmission or the revelation of its contents in any manner to an unauthorized person is prohibited by law.

ABSTRACT

For a 10° port rudder setting (horizontal rudders neutral) and for all yaw angles between -4° and $+10^\circ$, it was found that the moment coefficient with 2 and 4 pipes was practically the same as with no pipes.

For a 10° down rudder (vertical rudders neutral) and zero pitch angle, the rudder effect for the 4-pipe arrangement is 30% less than with no pipes, and for the 2-pipe arrangement the rudder effect is 45% greater. It is believed that the greater effect with the 2 pipes is due to the shielding of the rudders by the pipes.

The drag coefficient for the model at zero yaw and pitch is practically 0.13 for the 4-pipe, 2-pipe, and no-pipe arrangements.

The torpedo with a single exhaust pipe will have about 15% more drag than with any of the other exhaust arrangements. With a *down* setting of the horizontal rudders there will be less rudder effect with a single exhaust pipe than with the other exhaust arrangements due to the single pipe acting as an *up* rudder.

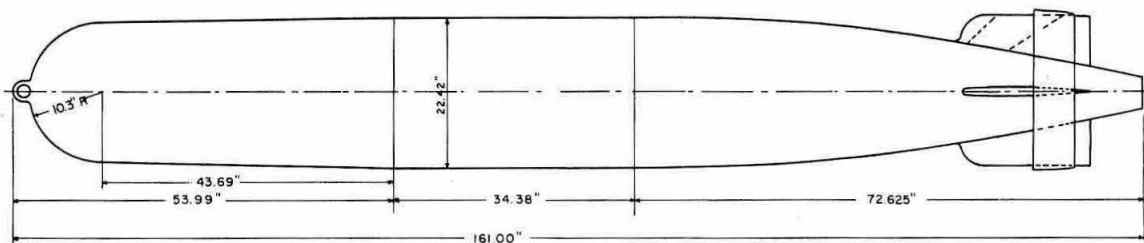


FIG. 1 - OUTLINE OF MK 25 TORPEDO

MK 25 TORPEDO
WITH
VARIOUS EXHAUST PIPES

GENERAL

This report covers force tests of a Mk 25 Torpedo model fitted with various types of exhaust pipes. The tests were conducted at the Hydrodynamics Laboratory of the California Institute of Technology and were authorized by Dr. E. H. Colpitts, Chief of Section 6.4, National Defense Research Committee, in a letter dated May 4, 1944.

This report is the third supplement to the report, Section No. 6.4-sr207-1275. The tests were for the purpose of determining the drag, cross force, lift and moment coefficients for the projectile when fitted with several different exhaust pipe designs and for various rudder settings.

In the normal design of existing gas turbine-driven torpedoes the exhaust gas is discharged through a hollow propeller shaft. In order to eliminate many of the objections to this arrangement, a new design has been made providing for the gas discharge through a fin or through 1, 2, or 4 pipes attached to the ring tail. In the case of the 4-pipe design, the ring is hollow to provide for the supply of gas to the pipes.

Reports, Section Nos. 6.4-sr207-1275, 1640, 1642, and 1916 cover studies of the cavitation effect, on rudders and propellers, of these various means of exhausting the gas.

All data herein refer to the prototype unless otherwise stated.

The appendix contains definitions of terms used in this report and other pertinent data.

DESCRIPTION OF PROJECTILE

Following are the principal dimensions of the projectile:

Diameter	22.42 inches
Length Overall	161.00 inches
Distance, Nose to C.G.	73.82 inches
Scale Ratio of Model	1 to 11.21

Figure 1 shows a general outline drawing of the projectile fitted with the standard nose that was used for all tests.

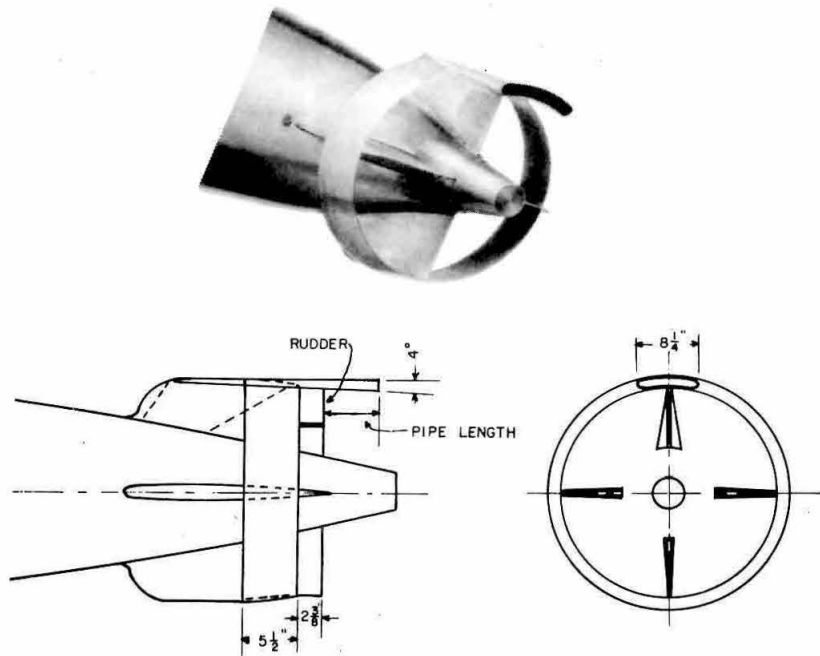


FIG. 2 - RING TAIL WITH SINGLE EXHAUST PIPE

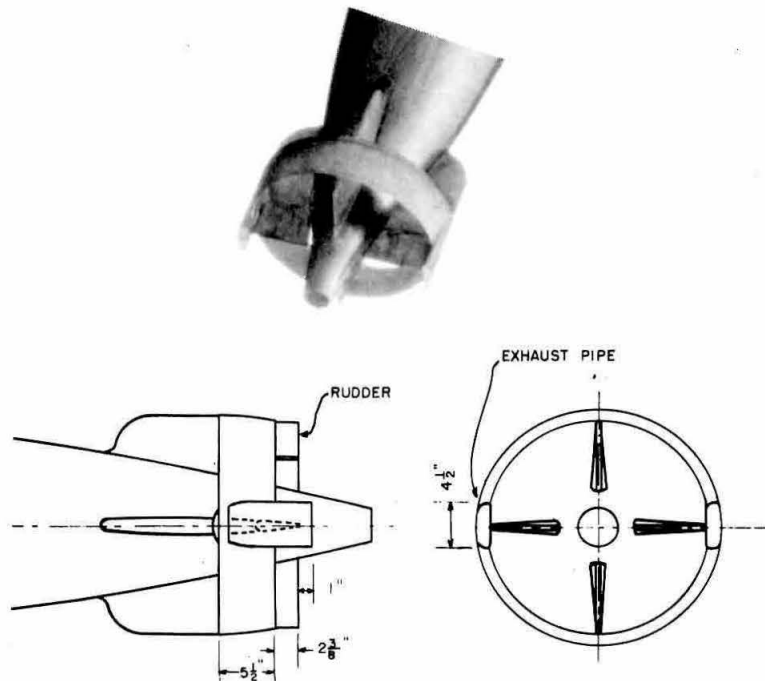


FIG. 3 - RING TAIL WITH TWO EXHAUST PIPES

In the prototype, the exhaust gas is passed through the hollow top vertical fin to the single exhaust pipe (Figure 2). The gas is fed to the two exhaust pipes through the hollow horizontal fins (Figure 3). In the 4-pipe arrangement, Figure 4,

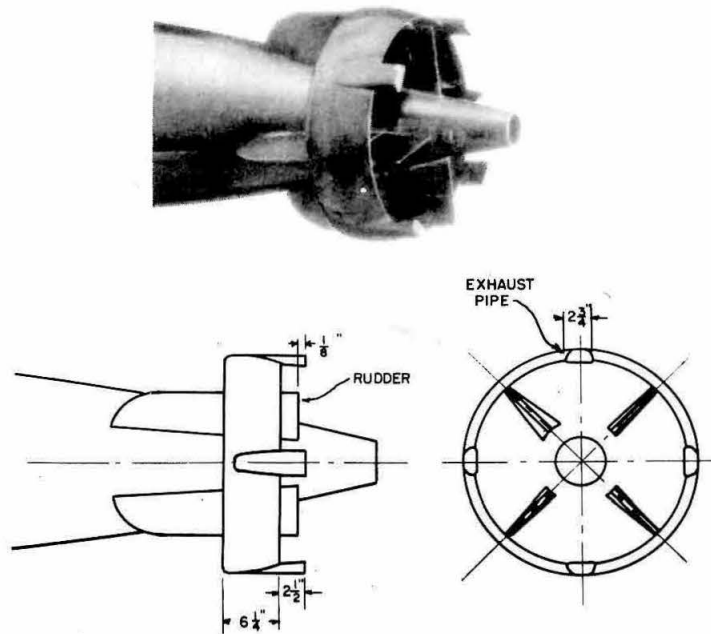


FIG. 4 - RING TAIL WITH FOUR EXHAUST PIPES

the ring is hollow, thus providing passage for the gas from the hollow horizontal fins to the pipes. As the hollow fins have an increased thickness, they might have some rudder effect, especially in the case of the single hollow top fin. In all of the model tests, for simplicity, the top vertical fin only was increased in thickness, regardless of the number of exhaust pipes. This introduces some asymmetry in the model that is not present in the prototype.

RING TAIL WITHOUT PIPES

Figure 5 is a photograph of the model ring tail without a discharge pipe, the exhaust being passed through the slot in line with the hollow top vertical fin.

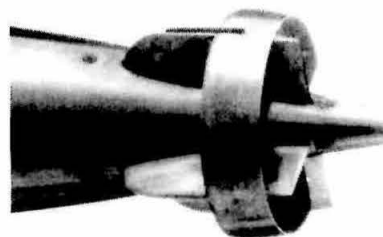


FIG. 5 - RING TAIL WITH NO PIPE. EXHAUST THROUGH SLOT IN RING

In Figure 6 the force coefficients are shown for 0° and 40° port settings for the vertical rudders and with neutral horizontal rudders. As would be expected, the cross force and moment curves for neutral rudders pass through zero as the projectile is symmetrical about the vertical center line. There is a slight stabilizing moment between 0° and 1° yaw for a 40° port setting of the vertical rudders.

In Figure 7 are shown the force coefficients for neutral vertical rudders and various settings of the horizontal rudders.

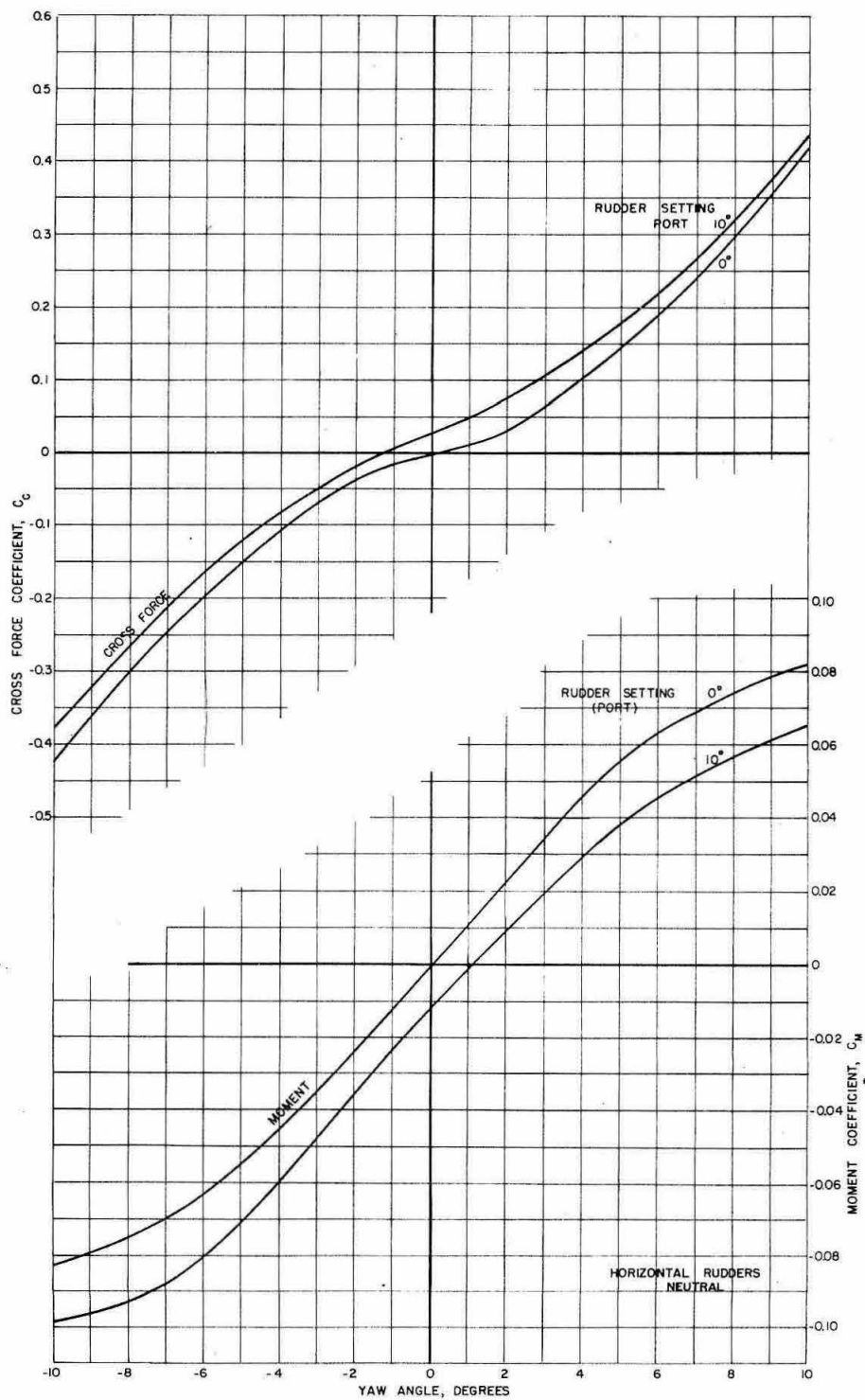


FIG. 6 - FORCE COEFFICIENTS WITH NO EXHAUST PIPE

Rudders: Vertical - 0° and 10° Port
Horizontal - Neutral

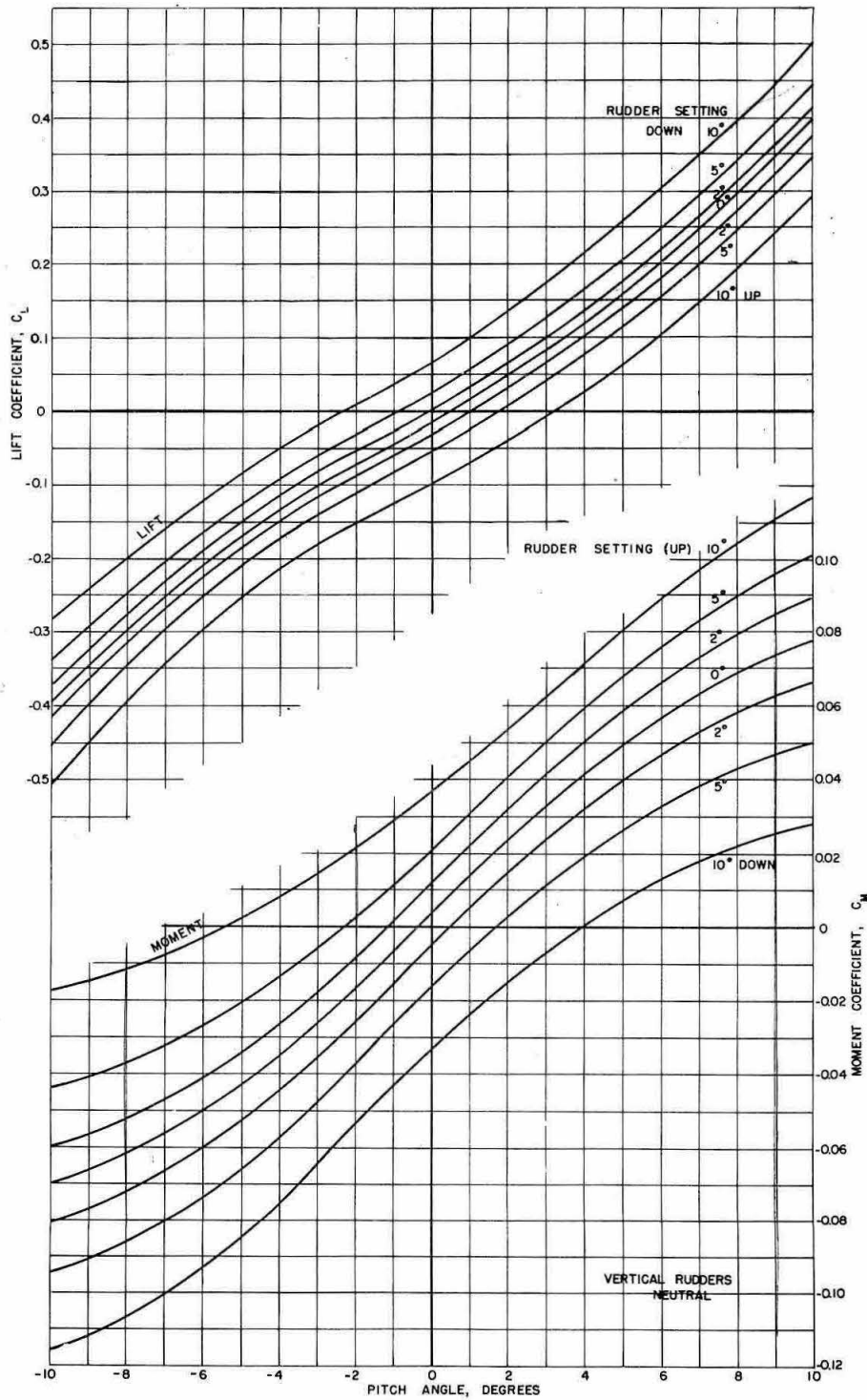


FIG. 7 - FORCE COEFFICIENTS WITH NO EXHAUST PIPE

Rudders: Vertical - Neutral
Horizontal - 0° , 2° , 5° , 10° up and down

The 0° , 2° , 5° , and 10° *up* rudder settings at 0° pitch angle result in stabilizing moment coefficients of 0.0004, 0.0013, 0.0022, and 0.0037, respectively. As can be seen from the curves, the stabilizing moments are somewhat less for corresponding *down* rudder settings. The slight stabilizing moment at zero rudder setting is very likely due to the thick top fin.

TWO EXHAUST PIPES

Figure 3 shows the ring tail with two exhaust pipes adjacent to the two horizontal fins.

The force coefficients for the projectile fitted with a ring tail and two pipes, as shown in Figure 8, are practically the same as for the ring without pipes (Figure 6) for the 0° and 10° port rudder settings. In Figure 9 it is seen that the 10° down setting of the horizontal rudders results in a moment coefficient of -0.048 at 0° pitch, which is about 50% greater than with no exhaust pipes. There is practically no rudder effect due to this exhaust pipe arrangement.

FOUR EXHAUST PIPES

Figure 4 shows the ring tail with four exhaust pipes.

Figures 10 and 11 show the force coefficients for this exhaust pipe arrangement.

A 10° port rudder setting with the 4-pipe arrangement results in a moment coefficient or rudder effect at zero yaw of 0.007 or only about 60% of that of the ring tail without pipes. The rudder effect for 10° down rudders with the 4-pipe design is about the same as for the 2-pipe design (Figure 9) with only a 5° down rudder setting. This symmetrical design results in practically no rudder effect with all rudders neutral.

SINGLE EXHAUST PIPE

Tests were run on the model with a ring tail fitted with a single exhaust pipe as shown in Figure 2. Figures 12 and 13 show the results of these tests which indicate that the moment coefficient with this single pipe is about the same as that for the other exhaust arrangements over a wide range of yaw angles. With a *down* setting of the horizontal rudders there is less rudder effect with a single pipe $3/4$ " long than with any of the other exhaust pipe arrangements. This is due to the single projecting pipe acting as an *up* rudder. This would tend to increase the rudder effect with an *up* rudder, as is seen in Figure 13. The variation in moment with pitch angle for a $5-1/2$ " single pipe was not at all consistent with the results obtained with the other exhaust arrangements. This discrepancy was probably due to rudder effect caused by some unnoticed misalignment of the long single pipe.

It is apparent that the single exhaust pipe will produce a greater destabilizing moment with varying pitch angles than is obtained with the other exhaust arrangements. It also appears that the single pipe design increases the drag about 15%.

COMPARATIVE RESULTS

In Figure 14 have been combined the force coefficient curves for the four exhaust arrangements discussed herein. The plain ring tail with no exhaust pipe gives the highest destabilizing moment with all rudders neutral, and the 4-pipe design gives the lowest.

The moment coefficient curves for 10° port and also 10° down rudder settings have been combined, for comparison, in Figure 15. For the 10° port rudder setting there is little variation in the moment coefficient for the three exhaust arrangements for yaw angles between -4° and $+10^\circ$. With the vertical rudders neutral, a 10° setting of the horizontal rudders results in a stabilizing moment for small pitch angles with all exhaust arrangements, although there are wide variations in the rudder effect. It is suggested that the greater rudder effect with the 2-pipe design is due to the shielding of the end of the rudder by the pipe, thereby increasing the effectiveness of the rudder.

The following table gives data taken from Figure 15:

<u>Vertical Rudders Neutral -- Horizontal Rudders 10° Down</u>	
<u>Exhaust Arrangement</u>	<u>Rudder Effect C_M at 0° Pitch</u>
4 pipes	--0.023
No pipes	--0.033
2 pipes	--0.048
1 pipe 3/4" long	--0.042

The drag coefficient was determined for the no-pipe, 2-pipe, and 4-pipe arrangements, and in all cases the drag decreased with increasing yaw and pitch angles. It is believed that this condition is not in accord with the facts, although the cause has not yet been investigated. The drag observations made at zero yaw angle are thought to be substantially correct for comparison of model performance. These are tabulated below, and it is seen that the addition of 2 or 4 pipes increases the drag very little. These drag measurements were made on a 2-inch diameter model at a water velocity of 32.4 ft/sec so the value for the prototype would be appreciably lower.

<u>Exhaust Arrangement</u>	<u>Drag Coefficient for Zero Yaw and Pitch</u>
No pipes	0.12
2 pipes	0.13
4 pipes	0.13
1 pipe 3/4" long	0.15

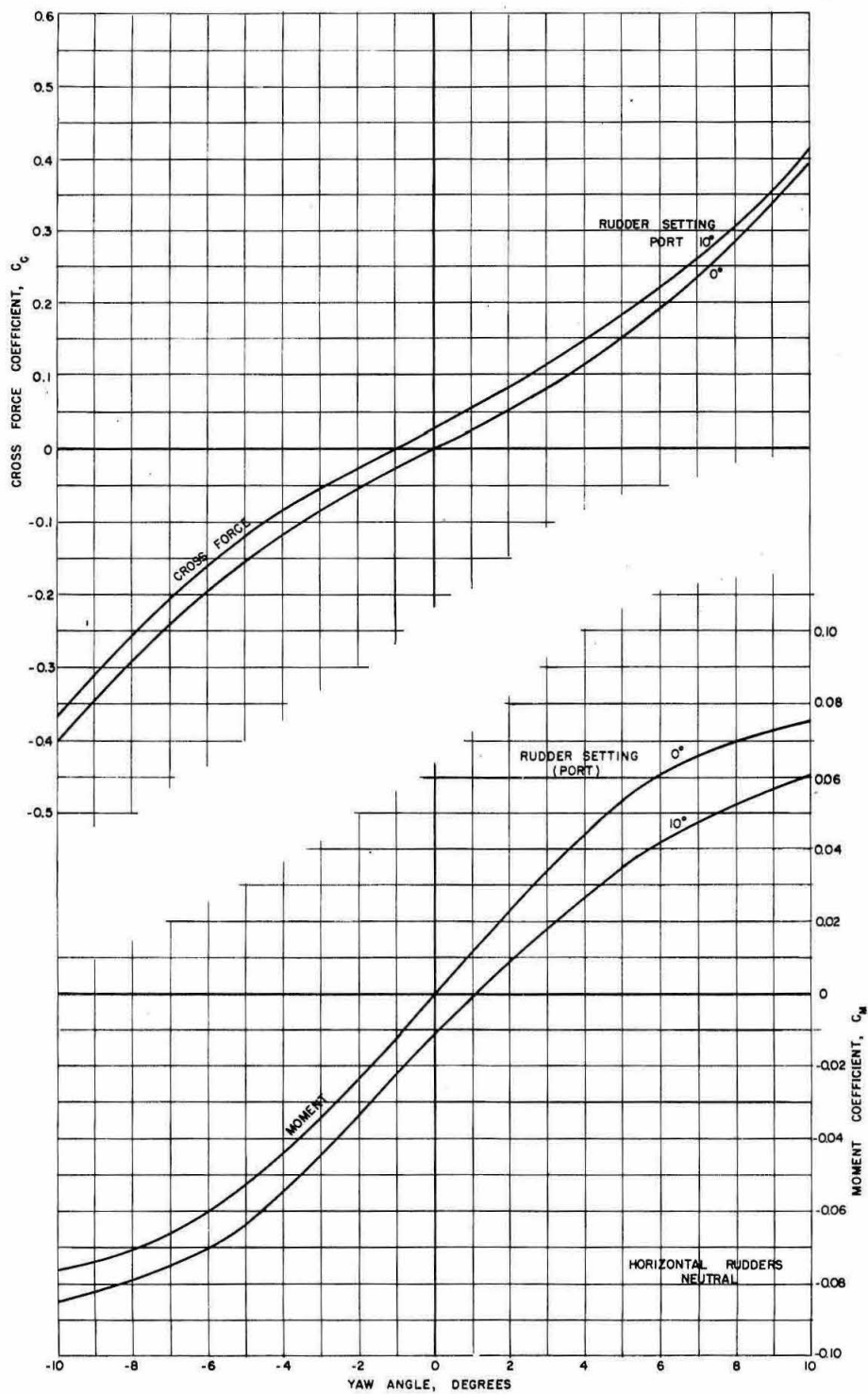


FIG. 8 - FORCE COEFFICIENTS FOR RING TAIL WITH TWO PIPES

Rudders: Vertical - 0° and 10° Port
Horizontal - Neutral

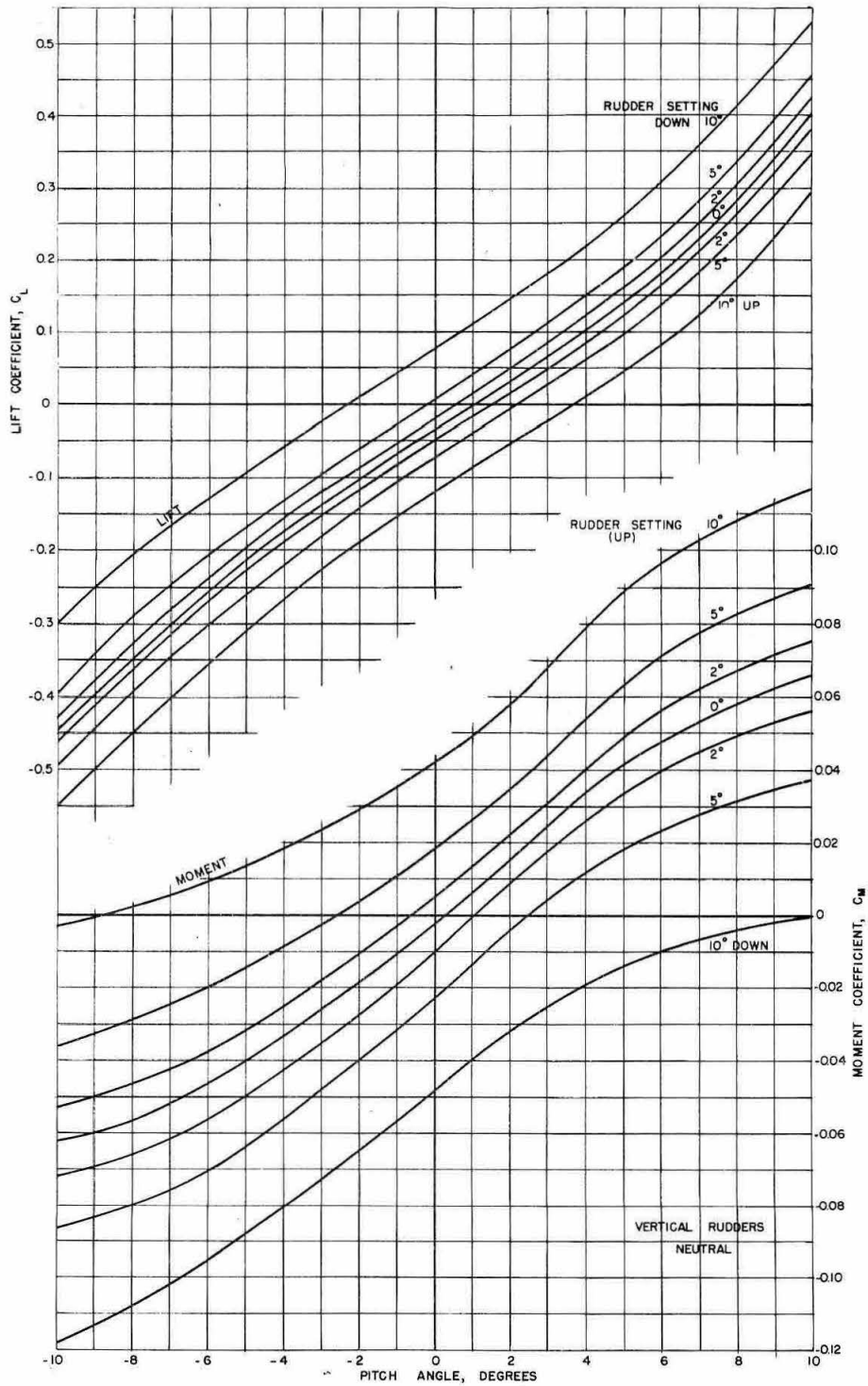


FIG. 9 - FORCE COEFFICIENTS FOR RING TAIL WITH TWO PIPES

Rudders: Vertical - Neutral
Horizontal - 0°, 2°, 5°, 10° up and down

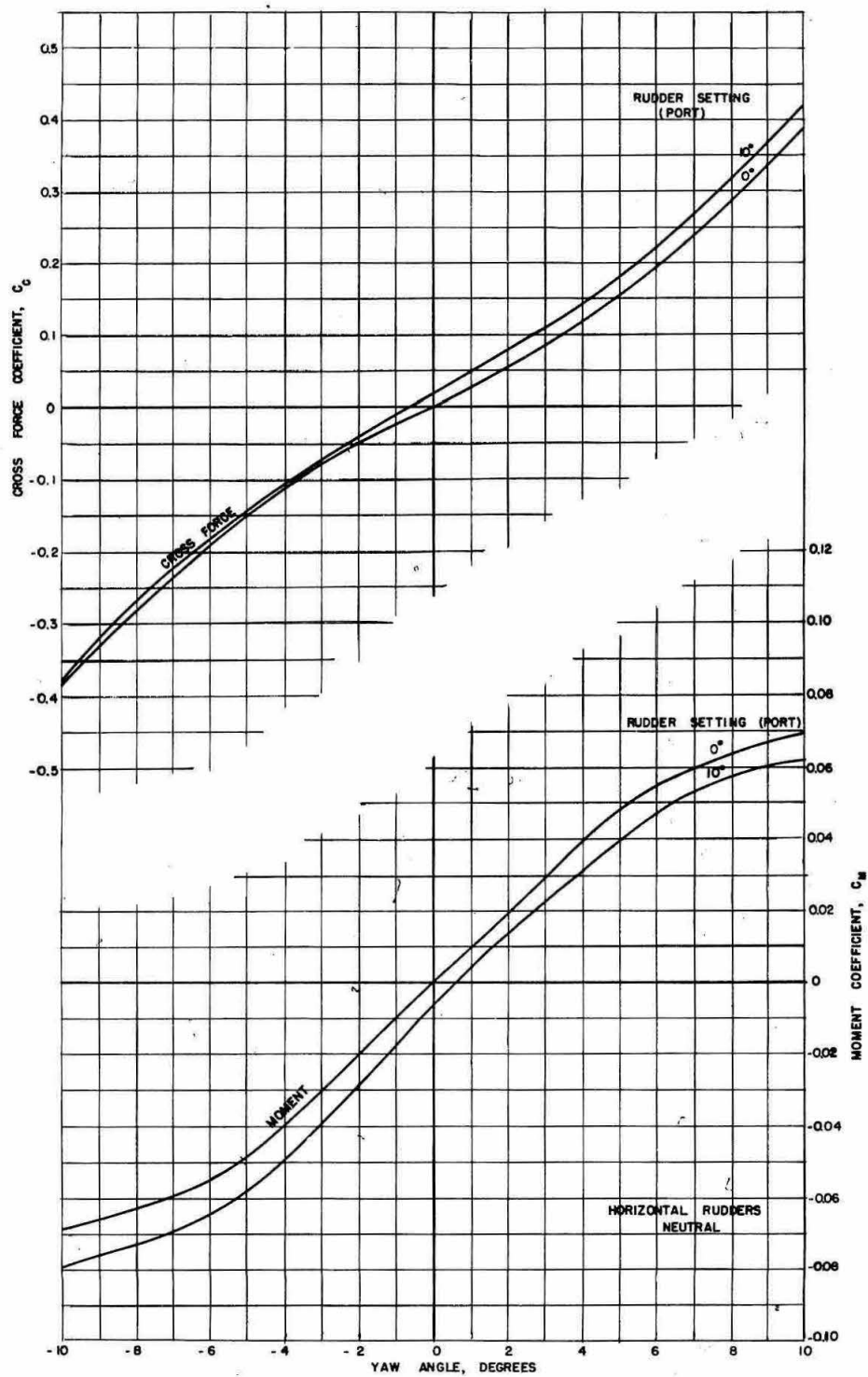


FIG. 10 - FORCE COEFFICIENTS FOR RING TAIL WITH FOUR PIPES

Rudders: Vertical - 0° and 10° port
Horizontal - Neutral

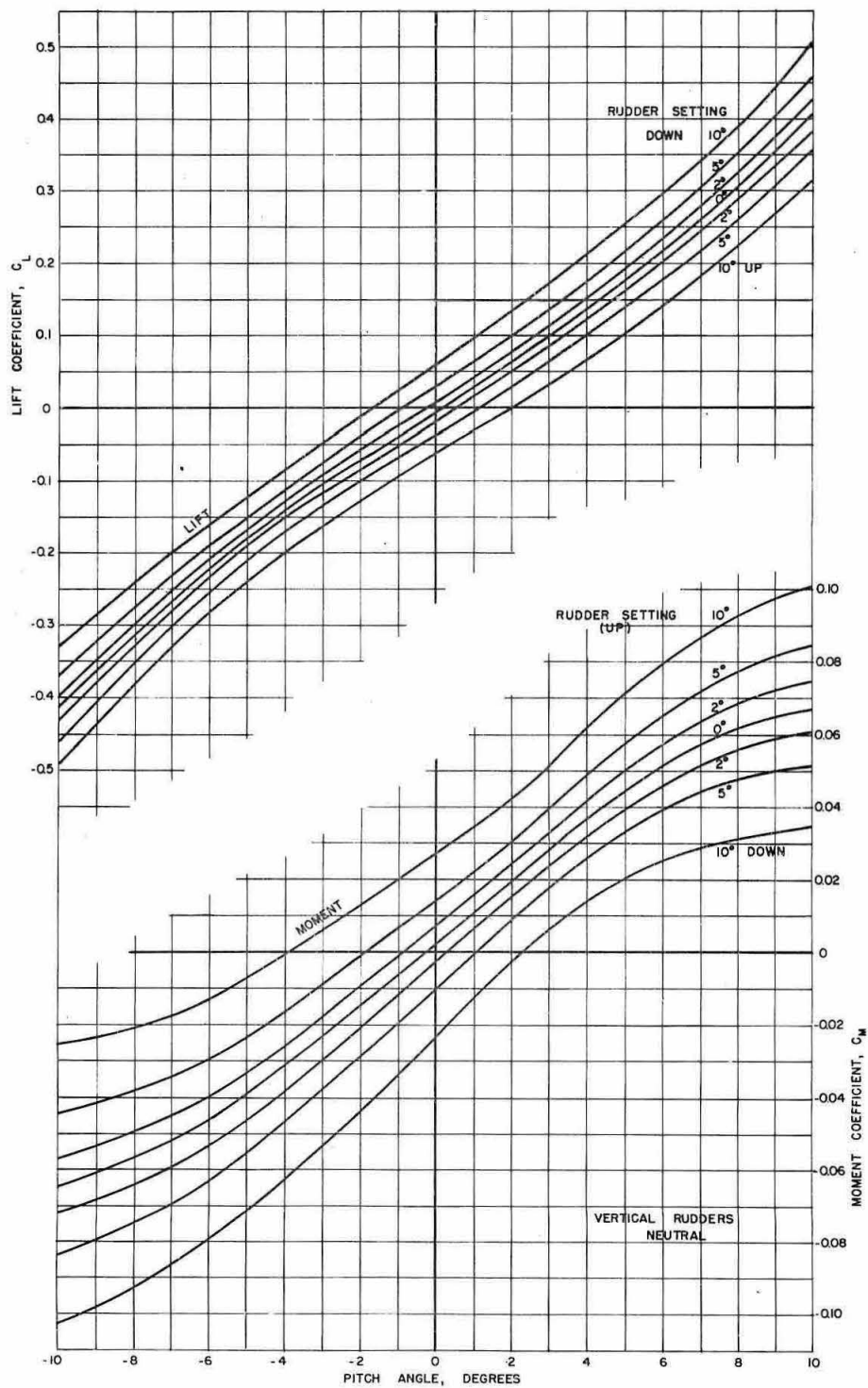


FIG. 11 - FORCE COEFFICIENTS FOR RING TAIL WITH FOUR PIPES

Rudders: Vertical - Neutral
Horizontal - 0°, 2°, 5°, 10° up and down

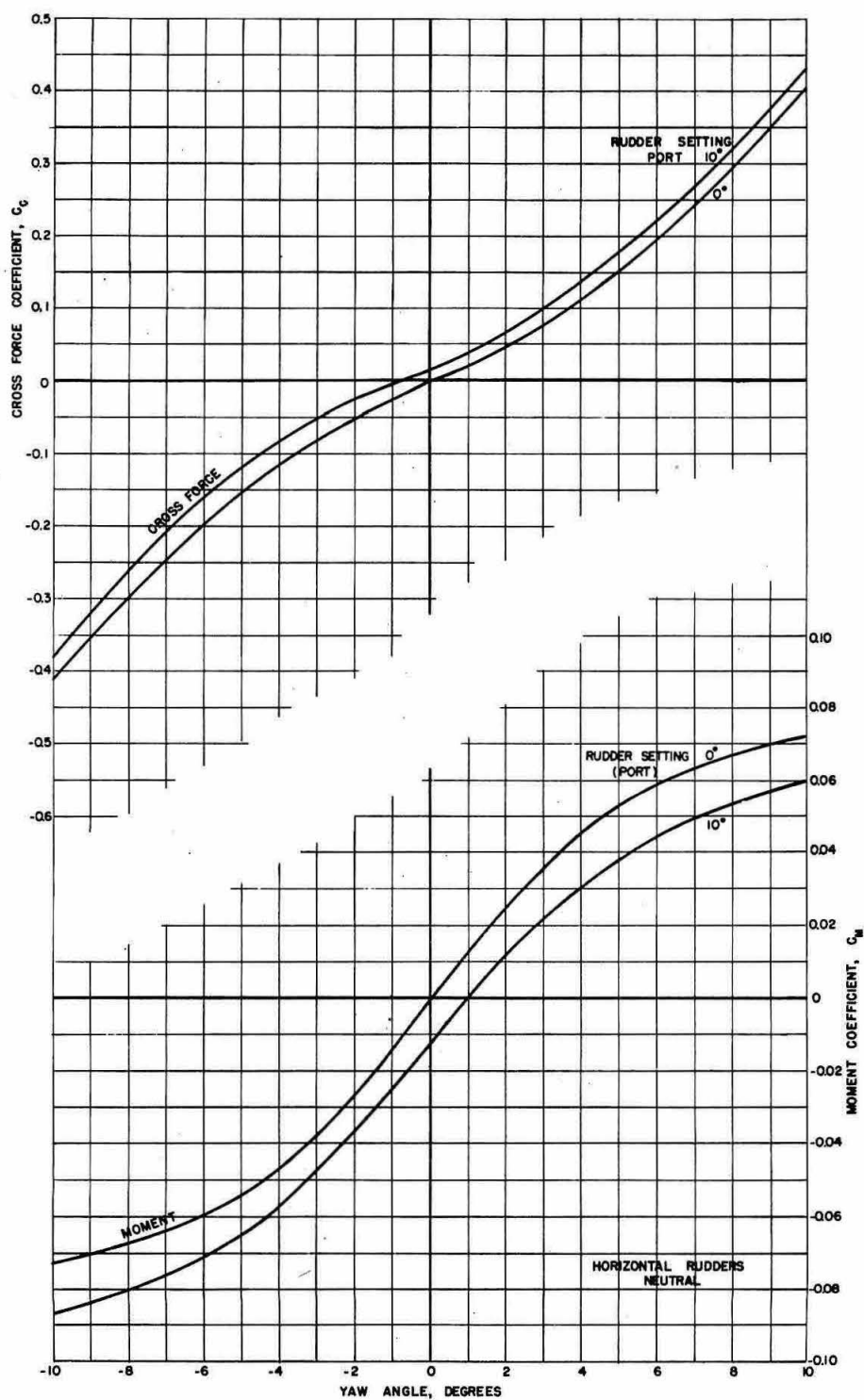


FIG. 12 - FORCE COEFFICIENTS FOR SINGLE PIPE 3/4" LONG

Rudders: Vertical - 0° and 10° Port
Horizontal - Neutral

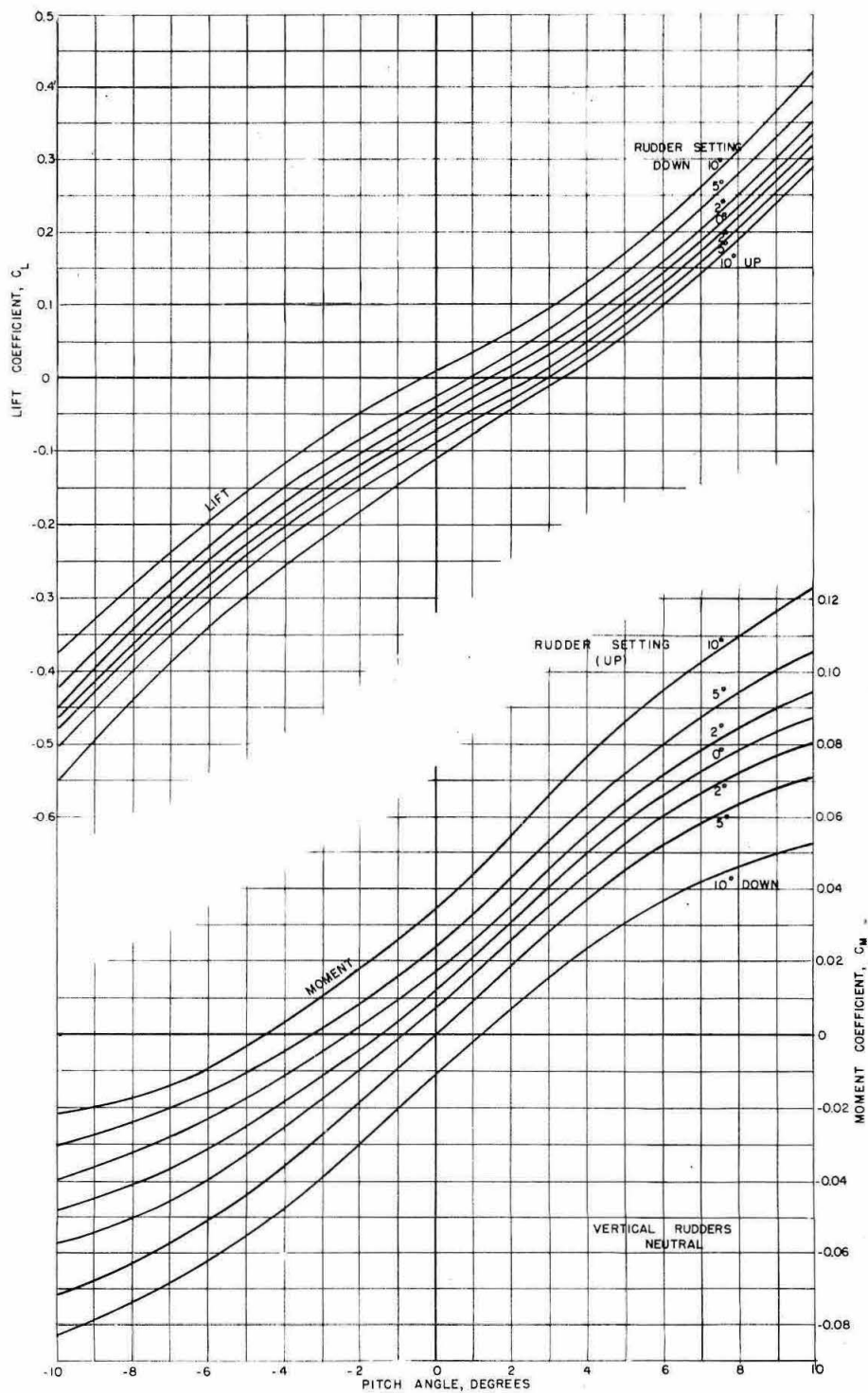


FIG. 13 - FORCE COEFFICIENTS FOR SINGLE PIPE 3/4" LONG

Rudders: Vertical - Neutral

Horizontal - 0°, 2°, 5°, 10° up and down

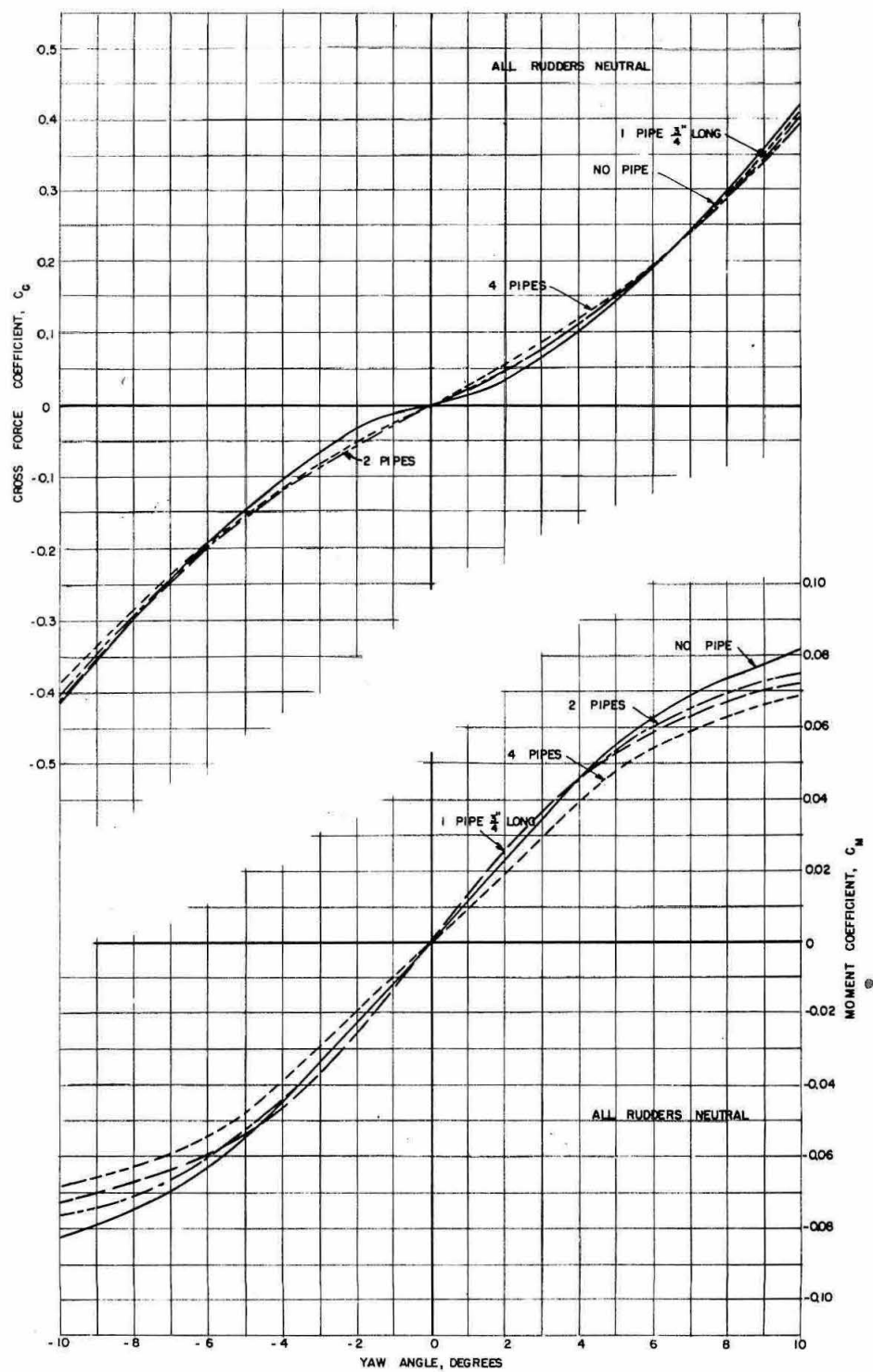


FIG. 14 - CROSS FORCE AND MOMENT COEFFICIENTS FOR RING TAIL
WITH VARIOUS EXHAUST PIPES

All Rudders Neutral

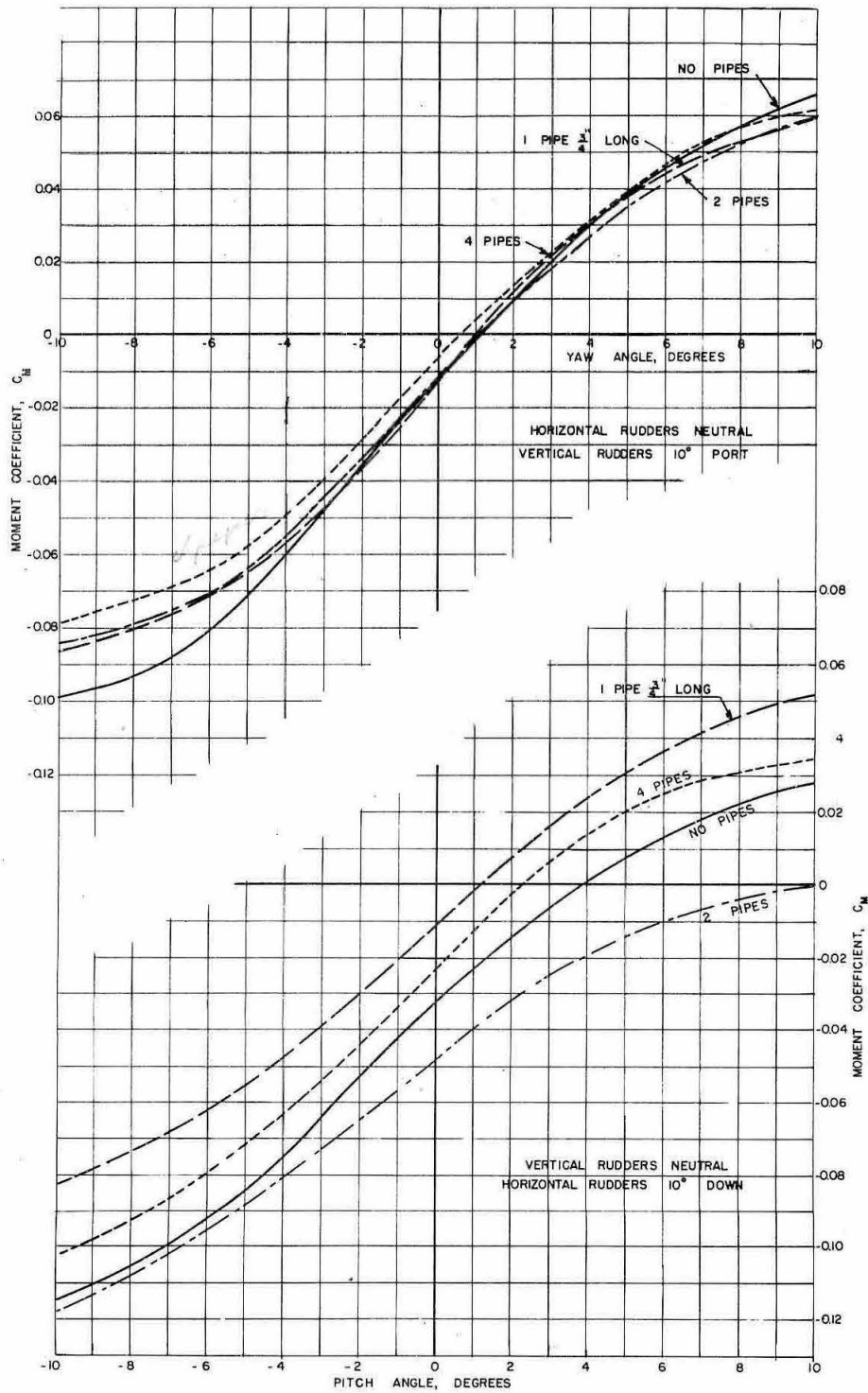


FIG. 15 - MOMENT COEFFICIENTS, RING TAIL WITH VARIOUS EXHAUST PIPES

Rudders: Vertical - 10° Port, Horizontal - Neutral
 Vertical - Neutral, Horizontal - 10° Down

APPENDIX

DEFINITIONS

YAW ANGLE, ψ

The angle, in a horizontal plane, which the axis of the projectile makes with the direction of motion. Looking down on the projectile, yaw angles in a clockwise direction are positive (+) and in a counterclockwise direction, negative (-).

PITCH ANGLE, α

The angle, in a vertical plane, which the axis of the projectile makes with the direction of motion. Pitch angles are positive (+) when the nose is up and negative (-) when the nose is down.

LIFT, L

The force, in pounds, exerted on the projectile normal to the direction of motion and in a vertical plane. The lift is positive (+) when acting upward and negative (-) when acting downward.

CROSS FORCE, C

The force, in pounds, exerted on the projectile normal to the direction of motion and in a horizontal plane. The cross force is positive when acting in the same direction as the displacement of the projectile nose for a positive yaw angle, i.e., to an observer facing in the direction of travel, a positive cross force acts to the right.

DRAW, D

The force, in pounds, exerted on the projectile parallel with the direction of motion. The drag is positive when acting in a direction opposite to the direction of motion.

MOMENT, M

The torque, in foot pounds, tending to rotate the projectile about a transverse axis. Yawing moments tending to rotate the projectile in a clockwise direction (when looking down on the projectile) are positive (+), and those tending to cause counterclockwise rotation are negative (-). Pitching moments tending to rotate the projectile in a clockwise direction (when looking at the projectile from the port side) are positive (+), and those tending to cause counterclockwise rotation are negative (-).

In accordance with this sign convention a moment has a de-stabilizing effect when it has the same sign as the yaw or pitch angle.

In all model tests the moment is measured about the point of support. Moments about the center of gravity of the projectile have the symbol, M_{cg} .

NORMAL COMPONENT, N

The sum of the components of the drag and cross force acting normal to the axis of the projectile. The value of the normal component is given by the following:

$$N = D \sin \psi + C \cos \psi \quad (1)$$

in which

N = Normal component in lbs.

D = Drag in lbs

C = Cross force in lbs

ψ = Yaw angle in degrees

CENTER OF PRESSURE, CP

The point in the axis of the projectile at which the resultant of all forces acting on the projectile is applied.

CENTER-OF-PRESSURE ECCENTRICITY, e

The distance between the center of pressure (CP) and the center of gravity (CG) expressed as a decimal fraction of the length (l) of the projectile. The center-of-pressure eccentricity is derived as follows:

$$e = (l_{cp} - l_{cg}) \frac{1}{l} = \frac{1}{l} \frac{M_{cg}}{N} \quad (2)$$

in which

e = Center-of-pressure eccentricity

l = Length of projectile in feet

l_{cg} = Distance from nose of projectile to CG in feet

l_{cp} = Distance from nose of projectile to CP in feet

COEFFICIENTS

The three force and moment coefficients used are derived as follows:

$$\text{Drag coefficient, } C_D = \frac{D}{\rho \frac{V^2}{2} A_D} \quad (3)$$

$$\text{Cross force coefficient, } C_C = \frac{C}{\rho \frac{V^2}{2} A_D} \quad (4)$$

$$\text{Lift coefficient, } C_L = \frac{L}{\rho \frac{V^2}{2} A_D} \quad (4a)$$

$$\text{Moment coefficient, } C_M = \frac{M}{\rho \frac{V^2}{2} A_D l} \quad (5)$$

in which

D = Measured drag force in lbs.

C = Measured cross force in lbs

L = Measured lift force in lbs

ρ = Density of the fluid in slugs/cu ft = w/g

w = Specific weight of the fluid in lbs/cu ft

g = Acceleration of gravity in ft/sec²

A_D = Area in sq ft at the maximum cross section of the projectile taken normal to the geometric axis of the projectile

V = Mean relative velocity between the water and the projectile in ft/sec

M = Moment, in foot-pounds, measured about any particular point on the geometric axis of the projectile

l = Overall length of the projectile in feet

RUDDER EFFECT

The total increase or decrease in moment coefficient, at a given yaw or pitch angle, resulting from a given rudder setting. This increase or decrease in moment coefficient is measured from the moment coefficient curve for neutral rudder setting.

REYNOLDS NUMBER

In comparing hydraulic systems involving only friction and inertia forces, a factor called Reynolds number is of great utility. This is defined as follows:

$$R = \frac{lV}{\nu} = \frac{lV\rho}{\mu} \quad (6)$$

in which

R = Reynolds number

l = Overall length of projectile, feet

V = Velocity of projectile, feet per sec

ν = Kinematic viscosity of the fluid, sq ft per sec = μ/ρ

ρ = Mass density of the fluid in slugs per cu ft

μ = Absolute viscosity in pound-seconds per sq ft

Two geometrically similar systems are also dynamically similar when they have the same value of Reynolds number. For the same fluid in both cases, a model with small linear dimensions must be used with correspondingly large velocities. It is also possible to compare two cases with widely differing fluids provided l and V are properly chosen to give the same value of R.

CAVITATION PARAMETER

In the analysis of cavitation phenomena, the cavitation parameter has been found very useful. This is defined as follows:

$$K = \frac{P_L - P_B}{\rho \frac{V^2}{2}} \quad (7)$$

in which

K = Cavitation parameter

P_L = Absolute pressure in the undisturbed liquid, lbs/sq ft

P_B = Vapor pressure corresponding to the water temperature, lbs/sq ft

V = Velocity of the projectile, ft/sec

ρ = mass density of the fluid in slugs per cu ft = w/g

w = weight of the fluid in lbs per cu ft

g = acceleration of gravity

Note that any homogeneous set of units can be used in the computation of this parameter. Thus, it is often convenient to express this parameter in terms of the head, i.e.,

$$K = \frac{h_L - h_B}{\frac{v^2}{2g}} \quad (8)$$

where

h_L = Submergence plus the barometric head, ft of water

h_B = Pressure in the bubble, ft of water

It will be seen that the numerator of both expressions is simply the net pressure acting to collapse the cavity or bubble. The denominator is the velocity pressure. Since the entire variation in pressure around the moving body is a result of the velocity, it may be considered that the velocity head is a measure of the pressure available to open up a cavitation void. From this point of view, the cavitation parameter is simply the ratio of the pressure available to collapse the bubble to the pressure available to open it. If the K for incipient cavitation is considered, it can be interpreted to mean the maximum reduction in pressure on the surface of the body measured in terms of the velocity head. Thus, if a body starts to cavitate at the cavitation parameter of one, it means that the lowest pressure at any point on the body is one velocity head below that of the undisturbed fluid.

The shape and size of the cavitation bubbles for a specific projectile are functions of the cavitation parameter. If p_B is taken to represent the gas pressure within the bubble instead of the vapor pressure of the water, as in normal investigations, the value of K obtained by the above formula will be applicable to an air bubble. In other words, the behavior of the bubble will be the same whether the bubble is due to cavitation, the injection of exhaust gas, or the entrainment of air at the time of launching.

The cavitation parameter for incipient cavitation has the symbol K_i .

The following chart gives values of the cavitation parameter as a function of velocity and submergence in sea water.

GENERAL DISCUSSION OF STATIC STABILITY

Water tunnel tests are made under steady flow conditions, consequently the results only indicate the tendency of the steady state hydrodynamic couples and forces to cause the projectile to return to or move away from its equilibrium position after a

disturbance. Dynamic couples and forces including either positive or negative damping are not obtained. If the hydrodynamic moments are restoring the projectile, then it is said to be statically stable, if nonrestoring, statically unstable. In the discussion of static stability the actual motion following a perturbation is not considered at all. In fact, the projectile may oscillate continuously about an equilibrium position without remaining in it. In this case it would be statically stable, but would have zero damping and hence, be dynamically unstable. With negative damping a projectile would oscillate with continually increasing amplitude following an initial perturbation even though it were statically stable. Equilibrium is obtained if the sum of the hydrodynamic, buoyant, and propulsive moments equal zero. In general, propulsive thrusts act through the center of gravity of the projectile so only the first two items are important.

If a projectile is rotating from its equilibrium position so as to increase its yaw angle positively, the moment coefficient must increase negatively (according to the sign convention adopted) in order that it be statically stable. Therefore, for projectiles without controls or with fixed control surfaces, a negative slope of the curve of moment coefficient vs yaw gives static stability and a positive slope gives instability. For a projectile without controls, static stability is necessary for a successful flight unless stability is obtained by spinning as in the case of rifle shells. For a projectile with controls, stabilizing moments can be obtained by adjusting the control surfaces, and the slope of the moment coefficient, as obtained with fixed rudder position, need not give static stability. Where buoyancy either acts at the center of gravity or can be neglected, equilibrium is obtained when the hydrodynamic moment coefficient equals zero. For symmetrical projectiles this occurs at zero yaw angle, i.e., when the projectile axis is parallel to the trajectory. For nonsymmetrical projectiles, such as a torpedo when the rudders are not neutral, the moment is not zero at zero yaw but vanishes at some definite angle of attack. Where buoyancy cannot be neglected equilibrium is obtained when $C_M = -C_{Buoyancy}$, and the axis of the projectile is at some angle with the trajectory.

For symmetrical projectiles the degree of stability, or instability can be obtained from the center of pressure curves. If the center of pressure falls behind the center of gravity, a restoring moment exists giving static stability. If the center of pressure falls ahead of the center of gravity, the moment is nonrestoring, and the projectile will be statically unstable. The degree of stability or instability is indicated approximately by the distance between the center of gravity and the center of pressure. In general, for nonsymmetrical projectiles, the cross force or lift is not zero when the moment vanishes so that the center of pressure curve is not symmetrical and the simple rules just stated cannot be used to determine whether or not the projectile will be stable. In such cases careful interpretation of the moment curves is a more satisfactory method of determining stability relationship.

